

## Forage Nutritive Value in an Emulated Silvopasture

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### ABSTRACT

Incorporating trees into pastures may alter forage nutritive value. The objective of this study was to determine nutritive value in response to trees and slope position in an emulated (no animals) silvopasture. In 1995, black walnut (*Juglans nigra* L.) and honey locust (*Gleditsia triacanthos* L.) trees were planted within three block plots of predominantly tall fescue (*Lolium arundinaceum* (Schreb.) Darbysh.) pasture. Soils on the site, (Unison and Braddock) are fine, mixed mesic Typic Hapludults, well drained, with moderately steep slopes (10–25%). Trees were planted down slopes in rows to create low-, medium-, and high-tree densities at shoulder-, mid-, and toe-slope positions. Forage from sampling sites ( $n = 54$ ) under field treatment combinations was harvested May, June, and July in 2002 and 2003. Concentrations of neutral and acid detergent fiber (NDF, ADF), acid detergent lignin (ADL), crude protein (CP), total non-structural carbohydrate (TNC) and Ca, P, Mg, and K were determined. Few differences due to treatment were observed for NDF and ADF concentrations. Concentrations of TNC decreased with greater tree density and appeared to follow tree leaf growth. Crude protein concentrations were typically greater under honey locust trees. Forage mineral concentrations frequently were greater with increased tree density. Trees appear to have both positive and negative effects on forage nutritive value, and their effects on animal performance warrants further research.

**S**ILVOPASTURE is an agroforestry practice of planned interactions (Clason and Sharrow, 2000) among trees, forages, and livestock. Silvopasture systems can be designed to capture potential benefits from biological interactions among crop components and give emphasis to species diversity (Matson et al., 1997; Garrett and McGraw, 2000).

Improved nutritive value is one potential benefit that may be realized with silvopastures. Increased nutritive value or digestibility in response to trees and/or shade has been reported for both cool- (Krueger, 1981; Garrett and Kurtz, 1983) and warm-season species (Eriksen and Whitney, 1981). Nutritive value can be influenced by the presence of trees in silvopastures via morphological and physiological adaptations (Eriksen and Whitney, 1981; Allard et al., 1991; Kephart et al., 1992; Kephart and Buxton, 1993; Sharrow, 1999), in addition to changes in botanical composition (Brooks, 1951; Burner and Brauer, 2003) in response to micro-environmental conditions.

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Black walnut and honey locust trees have potential for Appalachian agroforestry because of their phenological suitability and potential to generate additional products. Both species leaf out late in spring, maintain sparse, open canopies during summer, and drop leaves early in fall. Black walnut produces both high value wood and generates an annual nut crop and can be managed for either or both outputs (Williams et al., 1997). Selected varieties of honey locust (e.g., ‘Millwood’) are of interest for their potential to produce high-energy pods that might serve as a valuable source of livestock feed (Wilson, 1991). The pulpy pods contain up to 350 g kg<sup>-1</sup> sugar, and yields are similar to an equivalent area of oat (*Avena sativa* L.; Smith, 1950). Millwood stems are also highly palatable, thus these trees need extra protection from wildlife or livestock before maturity; in a pasture setting new seedlings would likely be killed by grazing.

Despite the potential benefits of silvopastoral practices, very little research has been conducted with forages grown under temperate hardwoods. Comparisons of the effects of different deciduous tree species are lacking in North America. Furthermore, silvopastoral research needs to be conducted in regionally appropriate field studies to account for differences in climate and differences in tree and forage production among other factors. Our objective for this study was to evaluate nutritive value of cool-season pastures in response to tree species, tree densities, and slope positions.

### MATERIALS AND METHODS

#### Site Description and Management

This research was conducted at Virginia Tech’s Kentland Farm near Blacksburg, VA. Site description, weather conditions, soil description, and management practices have been reported previously (Buerghler et al., 2005). Precipitation over the study season was well below average in 2002 and well above average in 2003. Soils on the site are fine, mixed mesic Typic Hapludults.

In 1995, black walnut and honey locust trees were planted in existing cool-season pastures. Three replicates each contained both a black walnut and a honey locust plot, and each tree plot contained four rows of trees. The four tree rows were planted in parallel and down the face of the 12% slope. Tree rows had a southwest to northeast orientation. For each tree plot, the distances between rows and between trees within rows were successively decreased from east to west, creating a tree density gradient both across and up the slope. Within each plot, the four rows of trees were spaced 14.6, 7.3, and 3.7 m apart; trees within rows were spaced 14.6, 7.3, 3.7, and 1.8 m apart.

Pastures were predominantly tall fescue, but contained orchardgrass (*Dactylis glomerata* L.), bluegrass (*Poa pratensis*

**Abbreviations:** ADF, acid detergent fiber; ADL, acid detergent lignin; CP, crude protein; NDF, neutral detergent fiber; PAR, photosynthetically active radiation; TNC, total nonstructural carbohydrate.

L.), and clovers (*Trifolium* spp.) among other forages. Buegler et al. (2005) reported differences in botanical composition due to season and treatment, with decreased fescue and increased clover observed under conditions of high rainfall. After tree establishment, pastures were maintained by clipping two or three times per season and broadcast applications of maintenance-level fertilization (N or complete fertilizer, <25 kg of nutrient) each fall. In October 2001, pastures were fertilized with 39 kg N ha<sup>-1</sup> (as urea). In October 2002, a blend of N, P and K was applied at rates of 45, 78, and 22 kg ha<sup>-1</sup>, respectively, in addition to 3.4 Mg ha<sup>-1</sup> of lime according to soil test.

### Field Layout and Sampling Procedures

Sampling sites ( $n = 54$ ) were located at points across the combination of slope and tree density factors to determine the influence on forage nutritive value. Nine permanent sites were created across the combination of low-, medium- and high-shade environments at shoulder- (top, nearly level), mid- (on the slope) and toe-slope (base of the slope, nearly level) positions within each tree plot ( $n = 18$  sites per replicate). Sampling-site locations were selected based on tree densities designed to create three shade classes: (i) full to partial shading all day, high shade environment or high tree density; (ii) morning sun exposure with shading events after solar noon, medium shade environment or medium tree density; and (iii) full exposure to sunlight from mid-morning, low shade environment or low tree density. The sampling sites, 0.53 by 2.44 m, were placed long-side parallel and approximately centered between the tree rows.

Soils were sampled in August 2002 to characterize pH and nutrient concentrations of the top 5 cm of the soil profile. Three, 2.5-cm wide cores were taken randomly from each site, mixed, dried, and ground. Soil Ca, P, Mg, and K analyses were conducted at the Virginia Tech Soil Testing Laboratory. Soil N and C were determined using a PerkinElmer CNS analyzer (Norwalk, CT).

Soil temperatures were determined at 3-h intervals from 0600 to 1800 h before harvest in July 2002 and again in August. In 2003, temperatures were recorded from 0900 to 1800 h from April through July. On the same dates that soil temperatures were recorded, soil moisture was measured at 1800 h by time domain reflectometry.

Photosynthetically active radiation data were collected in late summer of each year. Measurements were taken in the third block at all densities but only at shoulder- and toe-slope positions using LI-COR LI-191-SB line quantum sensors (LI-COR, Lincoln, NE) mounted parallel to tree rows. Under high-density tree plantings, sensors were placed in the middle of the first two tree rows (1.8 m from either row). For readings under medium-density tree plantings, sensors were placed under the drip line, 1.8 m from the second row of trees. Sensors at low-density sites were midway between trees in the 14.6-m-spaced tree row. Sensors were placed about 25 cm above the ground to prevent shading by forages. Sensor data was collected with Campbell Scientific 21X (Campbell Scientific, Logan, UT) data loggers.

Measurements of PAR were collected every 10 s and averaged hourly. These data also were screened to minimize confounding due to cloud cover within and among weeklong sampling periods. For each hour, the highest average value for open-site PAR within the sampling period was determined, and PAR measures from all densities at these time points were analyzed.

Plot herbage was cut and removed in September 2001 and November 2002, before the start of the study in the following

season. Forage sampling began each season when average forage canopy was about 25 cm tall (7–9 May). Sampling sites were cut to 7.5-cm-stubble height with a push mower with bag attachment, and harvests began after 1400 h to minimize effects of diurnal variation (Burner and Belesky, 2004). After harvest, entire mower-strip samples were dried at 60°C for 48 h and ground to pass a 1-mm screen with a hammer mill before analysis.

### Fibers, Lignin, Nonstructural Carbohydrate, and Crude Protein Analyses

Neutral detergent fiber, ADF, ADL, CP, and TNC were determined by near infrared reflectance spectroscopy (NIRS, Foss NIRSystem 6500M, Silver Spring, MD). Samples were scanned with near infrared radiation from 1100 to 2500 nm, and log (1/reflectance) was recorded. A stepwise multiple regression equation was generated for each forage constituent using the program SUBSET. Optimum equations were selected based on low standard errors of calibration and validation, and large coefficients of determination ( $r^2$ ) for calibration and performance. These were derived by regressing predicted data against actual data using a subset of forage samples. Samples for calibration subsets for each assay were selected by WIN ISI Wincan software version 1.5 (Infrasoft International LLC, Port Matilda, PA). Prediction equations for each analyte were based on all harvests over both growing seasons.

For the calibration set, a subset of samples was analyzed by wet chemistry. Concentrations of NDF, ADF, and ADL were determined sequentially with an ANKOM fiber analysis system (ANKOM Technology, Macedon, NY). Samples were analyzed in duplicate. A 3% coefficient of variation between samples was the critical limit for repeating the analysis. Forage CP concentrations were determined at the Virginia Tech Forage Testing Laboratory using Kjeldahl 2400 with a Foss Tecator (AN 300, AN 3001, Sweden). Procedures of Denson et al. (1990) were used for determination of TNC.

### Mineral Analyses

For determination of Ca, P, Mg, and K, ground forage samples were prepared by drying to constant weight at 60°C for 24 h. A 0.5-g subsample was then weighed into ignition tubes and ashed at 500°C in a muffle furnace for 24 h. Ash was dissolved in 10 mL of 6 M HCl, vortexed, and allowed to sit for 1 h before dilution to 50-mL final volume with distilled water. Samples were then refrigerated in scintillation vials before determination by atomic emission with an inductively coupled plasma spectrometer at the Virginia Tech Soil Testing Laboratory.

### Statistical Analysis

The two tree species were arranged in a randomized complete block design. Slope and density treatments were arranged as split block factors, creating a  $3 \times 2 \times 3$  randomized complete split-split block design. Data were analyzed as repeated measures in time using the General Linear Model procedure of SAS (SAS Institute, 2004). Replicate and slope position were main factors in the whole plot, with tree species and tree stand density as sub-, and sub-sub-plots, respectively. Years were analyzed separately due to differences in weather and botanical composition (Buegler et al., 2005). Harvests were treated as fixed effects and all main effects and their interactions were tested across and within harvest dates within years (Table 1). Means were separated by LSD, and treatments

**Table 1.** Analysis of variance and significance of nutritive value responses to slope position†, tree species‡, tree density§, and harvest date in an emulated silvopasture.

Effect	NDF	ADF	ADL	TNC	CP	Ca	P	Mg	K
<b>2002</b>									
Slope	NS	*	NS	NS	*	*	*	NS	*
Species	NS	NS	*	*	NS	*	NS	NS	NS
Slope × species	NS	NS	NS	*	NS	NS	NS	NS	NS
Density	NS	NS	NS	**	NS	*	*	NS	NS
Slope × density	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species × density	NS	NS	NS	NS	NS	NS	NS	NS	NS
Slope × species × density	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date	**	**	**	**	**	**	**	**	**
Slope × date	*	**	NS	**	**	NS	**	NS	**
Species × date	**	**	**	**	**	**	**	*	**
Slope × species × date	NS	*	**	**	NS	NS	NS	NS	NS
Density × date	*	*	*	*	*	*	*	*	*
Slope × density × date	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species × density × date	NS	NS	**	NS	*	NS	NS	NS	**
Slope × species × density × date	NS	NS	NS	NS	NS	NS	*	NS	NS
<b>2003</b>									
Slope	NS	*	NS	NS	NS	NS	NS	NS	NS
Species	*	NS	*	**	*	**	NS	NS	NS
Slope × species	NS	NS	NS	*	NS	NS	NS	NS	NS
Density	NS	NS	**	**	NS	*	*	**	**
Slope × density	NS	NS	*	*	NS	NS	NS	NS	NS
Species × density	NS	NS	*	NS	NS	NS	NS	NS	*
Slope × species × density	NS	NS	NS	NS	NS	NS	NS	NS	NS
Date	**	**	**	**	**	**	**	**	NS
Slope × date	NS	NS	*	NS	NS	*	*	NS	**
Species × date	NS	NS	NS	NS	NS	**	**	**	NS
Slope × species × date	NS	NS	NS	NS	NS	**	*	NS	**
Density × date	*	*	*	*	*	*	*	*	*
Slope × density × date	NS	NS	NS	NS	NS	NS	NS	NS	NS
Species × density × date	NS	NS	NS	NS	NS	NS	NS	NS	NS
Slope × species × density × date	NS	NS	NS	NS	NS	NS	NS	NS	NS

\*  $P < 0.05$ .\*\*  $P < 0.01$ .

† Toe = 3–5% slope at base of hill, Mid = 10–15% slope at side of hill, Shoulder = 3–5% slope at top of hill.

‡ Tree species were black walnut (*Juglans nigra* L., BW) and honey locust (*Gleditsia triacanthos* L., HL).

§ Low density = almost full exposure to sunlight, low shade environment; Medium (Med) density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

were considered significant at  $P < 0.05$ . Where appropriate, trends ( $P < 0.10$ ) are reported but LSD is not noted.

## RESULTS AND DISCUSSION

### Climate, Trees, and Microclimate

The 2002 study year was characterized by drought, followed by unusually high rainfall during summer 2003. Total precipitation for the period was 30.5 and 60.8 cm in 2002 and 2003 compared with long-term mean total precipitation of 37.4 cm. Means of average hourly temperatures for April, May, June, and July of 2002 were 12.3, 14.9, 20.5, and 22.2°C and 11.2, 15.3, 18.8, and 21.3°C in 2003. Long-term mean monthly temperatures for the period are 10.6, 15.6, 19.7, and 21.9°C.

By the end of 2003, trees in the study were 10 yr old and approaching full canopy closure within the closest row spacings. Walnut trees had greater diameter at breast height at toe-slope (5.6 cm) than at mid- (3.5 cm) or shoulder-slope (2.9 cm) positions, but this measure was unaffected by slope in locust trees (mean = 5.6 cm) (species × slope interaction,  $P < 0.01$ ). Walnut trees were shorter ( $P < 0.01$ ) than locust trees (5.1 vs. 3.2 m) and both species tended ( $P = 0.07$ ) to be taller at toe- (4.7 m) than at mid- (3.9 m) and shoulder-slope positions (3.8 m).

At the black walnut toe-slope position, 2-yr mean total PAR (determined during periods of highest insolation) was 49.3, 21.8, and 15.7 mol m<sup>-2</sup> d<sup>-1</sup> for the low-, medium-, and high-tree density sites. Honey locust canopies were less dense than walnut at toe slopes and received PAR of 52.9, 37.8, and 31.3 mol m<sup>-2</sup> d<sup>-1</sup>. At the shoulder-slope position, mean PAR values for plots under low, medium, and high black walnut tree densities were 49.4, 38.6, and 39.9 mol m<sup>-2</sup> d<sup>-1</sup>, indicative of smaller, more uniform tree size on the upslope. Honey locust trees were less affected by slope position, and PAR values declined with density similar to reductions at toe slopes (53.1, 33.3, and 29.3 mol m<sup>-2</sup> d<sup>-1</sup>).

Soil temperatures at low-density sites were often greater than 24°C, the upper critical optimum temperature for some cool-season forages (Sprague, 1943). In 2002, the mean temperatures (measured at 3-h intervals from 900 to 1800 h in July and August) from low- to high-tree density were 31.5, 29.8, and 29.3°C. In cooler 2003, data were collected daily at 3-h intervals from 23 May through 31 July. During this period few temperature readings above 24°C were observed at 900 or 2100 h. From 1200 to 1800 h (representing 210 readings over the 70-d measurement period), 149, 124, and 103 hourly measures of soil surface temperature were greater than 24°C at low, medium- and high-density sites. During the 70-d period, mean temperatures across these

three measurement times (1200, 1500, and 1800 h) were 27.6, 25.5, 24.4°C. Thus, shade from trees likely modified temperatures to the benefit of cool-season grasses.

Soil moisture measures during June and July 2002 averaged 169, 137, and 136 g kg<sup>-1</sup> soil for toe-, mid-, and shoulder-slope positions. In 2003, measures were taken April through July, and differences among slope positions were smaller (296, 279, and 287 g kg<sup>-1</sup> soil) for these respective slope positions given the season's ample precipitation. Soil moisture under black walnuts was lower than under honey locust both in dry 2002 (133 and 155 g kg<sup>-1</sup> soil) and wet 2003 (274 vs. 301 g kg<sup>-1</sup> soil). Tree density appeared to have the least effect on soil moisture in either year, though values were generally greater at low-density sites (153, 142, and 147 g kg<sup>-1</sup> soil in 2002; and 293, 282, and 287 g kg<sup>-1</sup> soil in 2003). Although patterns were consistent across sampling times, significant treatment differences were rarely observed.

### Neutral Detergent Fiber

In 2002, NDF concentrations changed little at toe-slope positions while those at mid- and shoulder-slope positions were greater in June 2002 (slope × date interaction,  $P < 0.05$ , Tables 1 and 2). Slope effects ( $P < 0.05$ ) were observed again in May 2003 and for the mean of the 2003 harvests. Toe-slope positions appeared buffered from environmental extremes, in part as a function of cooler soil temperatures. Trees were smaller at mid- and shoulder slopes, allowing more radiant energy the reach the forage or soil surface, and greater soil temperatures were thus observed.

The NDF response to tree species varied by harvest (species × date interaction,  $P < 0.01$ ) (Table 1). With honey locusts, NDF concentrations were similar across harvest dates, but NDF levels were greater in June and July under black walnut (Table 2). In 2003, forages grown under honey locusts had lower ( $P < 0.05$ ) NDF concentrations at June and July harvests, with a similar tendency ( $P < 0.10$ ) in May (Table 2). This response to tree species appears due to the greater leguminous component of the sward observed under honey

locusts in 2003 (Buerger et al., 2005). Botanical separations were made in May and July 2003, and negative correlations between NDF and percentage legume were observed for each sampling event ( $-0.55$  and  $-0.68$ , respectively), when legumes made up about 11 and 31% of the sward, respectively.

Density × date interactions ( $P < 0.05$ ) for NDF were observed each season (Table 1), primarily due to date effects in 2002. Concentrations of NDF tended ( $P < 0.10$ ) to be lower at high tree density sites over the 2003 season, driven primarily by the large reduction ( $P < 0.01$ ) with density at the July 2003 harvest (Table 2). The small reductions in forage NDF with increasing tree densities are similar to changes reported for fescue grown under reduced irradiance (Kephart and Buxton, 1993; Lin et al., 2001). However, it is not clear if this effect is strictly from reduced light or whether reduced temperature also plays a role. Elevated ambient temperatures increase forage fiber concentrations in growing plants (Fales, 1986), and trees affected both temperature and available light in the growing environment.

### Acid Detergent Fiber

Forage ADF concentrations were much greater at mid- and shoulder-slope positions than at toe-slope positions in June 2002 (slope × date interaction,  $P < 0.01$ ) (Tables 1 and 3). Slope effects ( $P < 0.05$ ) were observed each year (Table 1). Both in 2002 and in 2003, ADF concentrations were about 15 g kg<sup>-1</sup> lower ( $P < 0.05$ ) at toe-slope positions (Table 3).

A species × date interaction ( $P < 0.01$ ) for ADF was observed in 2002 (Table 1). Forage from plots under honey locust trees had about 9 g kg<sup>-1</sup> greater ( $P < 0.05$ ) ADF concentrations than forage from black walnut plots in May and July 2002 (263 vs. 254 g kg<sup>-1</sup>). However, in June forage ADF concentrations were greater under black walnut at mid- and shoulder-slope positions (slope × species × date interaction;  $P < 0.05$ ) (Table 1).

No response to species was observed in 2003 (Table 1).

Tree density effects on ADF varied by date (density × date interaction,  $P < 0.05$ ) (Table 1), were less than 10 g

**Table 2. Neutral detergent fiber concentrations in a mixed sward in response to main effects of slope position, tree species, and tree density.**

Harvest	Slope position†			LSD‡¶	Tree species‡‡		LSD	Tree density§			LSD
	Toe	Mid	Shoulder		BW	HL		Low	Med	High	
	g kg <sup>-1</sup>										
					2002						
May	491	518	518	NS	501	517	NS	511	512	504	NS
June	498	548	548	32	538	524	NS	540	528	525	NS
July	507	532	520	NS	519	520	NS	518	517	524	NS
Mean	499	533	529	31	520	520	NS	523	519	518	NS
LSD	NS	14	17		18	NS		20	NS	NS	
					2003						
May	473	521	517	38	514	492	NS	505	508	498	NS
June	396	433	420	NS	433	400	19	415	426	408	NS
July	429	454	463	NS	461	436	18	456	458	433	14
Mean	433	469	467	32	470	443	18	459	464	447	NS
LSD	22	27	29		24	20		23	32	24	

† Toe = 3–5% slope at base of hill, Mid = 10–15% slope at side of hill, Shoulder = 3–5% slope at top of hill.

‡ Tree species were black walnut (*Juglans nigra* L., BW) and honey locust (*Gleditsia triacanthos* L., HL).

§ Low density = almost full exposure to sunlight, low shade environment; Medium (Med) density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

¶ For all treatment means,  $\alpha \leq 0.05$ .



**Table 3. Acid detergent fiber concentrations in a mixed sward in response to main effects of slope position, tree species, and tree density.**

Harvest	Slope position†			LSD‡¶	Tree species‡		LSD	Tree density§			LSD
	Toe	Mid	Shoulder		BW	HL		Low	Med	High	
	g kg <sup>-1</sup>										
					2002						
May	249	262	263	NS	253	263	9	258	258	258	NS
June	251	280	278	14	273	261	NS	274	271	265	NS
July	254	264	257	NS	255	262	6	254	257	263	NS
Mean	251	269	266	10	260	262	1	262	262	262	NS
LSD	NS	8	9		8	NS		10	11	NS	
					2003						
May	258	278	278	16	272	270	NS	269	271	272	NS
June	225	238	232	NS	234	230	NS	229	235	230	NS
July	248	262	265	NS	259	258	NS	259	262	255	NS
Mean	244	259	258	10	253	255	NS	252	256	252	NS
LSD	7	10	7		9	7		8	11	10	

† Toe = 3 to 5% slope at base of hill, Mid = 10 to 15% slope at side of hill, Shoulder = 3 to 5% slope at top of hill.

‡ Tree species were black walnut (*Juglans nigra* L., BW) and honey locust (*Gleditsia triacanthos* L., HL).

§ Low density = almost full exposure to sunlight, low shade environment; Medium (Med) density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

¶ For all treatment means,  $\alpha \leq 0.05$ .

kg<sup>-1</sup>, and were driven by slight changes in the magnitude of the response. Limited ADF response to tree density appears to agree with results of Lin et al. (2001), who reported that ADF levels were unaffected or slightly increased in potted forages grown under shade.

### Acid Detergent Lignin

Slope effects on ADL were obscured by a complex three-way interaction ( $P < 0.01$ ) in 2002 and two-way interactions ( $P < 0.05$ ) in 2003 (Table 1). In May 2002, ADL concentrations were similar between species at toe- and mid-slope positions but were greater for locusts at shoulder-slope positions (Table 4). For locusts, ADL concentrations increased with each successive harvest and were similar by slope position in 2002. In contrast, ADL concentrations under walnut were greatest in June and intermediate in July 2002, and for these two harvests ADL concentrations were lower at toe-slope positions. Slope  $\times$  date interaction ( $P < 0.05$ ) in 2003 was driven by lower ADL concentrations at mid- and shoulder-slope positions in June.

Concentrations of ADL tended ( $P < 0.10$ ) to increase with tree density in 2002 and were greater ( $P < 0.05$ ) with density in 2003 (Table 4). However, in 2003, ADL concentrations were greater under medium density trees at toe slopes (slope  $\times$  density interaction;  $P < 0.05$ ) (Table 1).

Forage ADL under honey locusts varied little (23.7 g kg<sup>-1</sup>) across density treatments but increased with increasing tree density (from 18.7–23.6 g kg<sup>-1</sup>) in forage grown under walnut (species  $\times$  density interaction,  $P < 0.05$ ). Increases in ADL with shade have been reported by others (Lewis et al., 1983; Samarakoon et al., 1990; Kephart and Buxton, 1993). Morphological adaptations to low light environments generally include increased internodal length and reduced specific leaf weight (Allard et al., 1991), with internodal tissues typically containing elevated levels of lignin.

### Total Nonstructural Carbohydrate

The response of forage TNC concentrations to slope position varied with tree species within each year

**Table 4. Acid detergent lignin concentrations in a mixed sward in response to main effects of slope position, tree species, and tree density.**

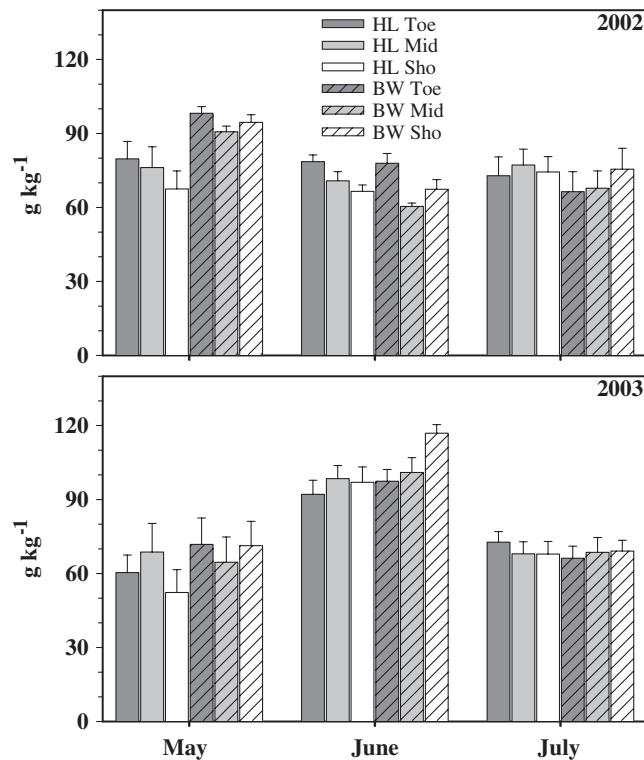
Harvest	Slope position†			LSD‡	Tree species‡		LSD	Tree density§			LSD
	Toe	Mid	Shoulder		BW	HL		Low	Med	High	
	g kg <sup>-1</sup>										
2002											
May	15.9	16.3	16.4	NS	15.1	17.3	1.9	15.0	16.6	17.1	NS
June	20.5	23.1	23.0	NS	22.2	22.2	NS	23.1	22.2	21.4	NS
July	21.7	22.3	22.6	NS	19.2	25.2	2.7	20.5	21.3	24.8	1.6
Mean	19.4	20.6	20.7	NS	18.9	21.6	1.7	19.5	20.0	21.1	NS
LSD	2.8	2.4	3.0		1.7	2.2		2.5	2.1	3.3	
2003											
May	17.1	17.6	16.0	NS	16.1	17.7	NS	15.1	17.1	18.6	1.7
June	22.6	18.8	19.4	NS	18.4	22.1	2.9	19.8	19.6	21.4	NS
July	29.1	30.5	29.4	NS	28.3	31.0	2.6	28.3	29.6	31.1	NS
Mean	22.9	22.3	21.6	NS	23.6	21.0	2.7	21.0	22.1	23.7	1.5
LSD	2.4	3.1	3.3		2.4	2.4		2.9	3.1	2.9	

† Toe = 3 to 5% slope at base of hill, Mid = 10 to 15% slope at side of hill, shoulder = 3 to 5% slope at top of hill.

‡ Tree species were black walnut (*Juglans nigra* L., BW) and honey locust (*Gleditsia triacanthos* L., HL).

§ Low density = almost full exposure to sunlight, low shade environment; Medium (Med) density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

¶ For all treatment means,  $\alpha \leq 0.05$ .



**Fig. 1.** Total nonstructural carbohydrate concentrations in response to tree species (HL = honey locust, BW = black walnut) and toe-, mid-, or shoulder- (Sho) slope position in Appalachian silvopastures harvested in May, June, and July in 2002 and 2003. Species effects ( $P < 0.05$ ) were observed in May and July of 2002 and May and June of 2003. Slope tended ( $P < 0.10$ ) to affect TNC in June of each year, and species  $\times$  slope interaction ( $P < 0.05$ ) was observed in June 2003.

(slope  $\times$  species interaction,  $P < 0.05$ ). In 2002, TNC concentrations in forage from under honey locust trees declined from toe- to shoulder-slope positions at May and June harvests, but TNC levels were lower only at mid-slope under walnut trees (Fig. 1). This pattern was reversed in July 2002, when forages at mid-slopes had

TNC concentrations equal or greater to TNC in forage from toe slopes, regardless of tree species. The TNC levels in forage from toe-slope positions in June 2002 reflect the dynamic effect of the tree canopy on forage TNC. A mid-May frost in 2002 settled on the toe slopes and froze back tree leaves at those sites. The tendency ( $P < 0.10$ ) of greater TNC at toe-slope positions in June 2002 indicates that toe slope trees had not fully recovered. However, differences due to slope or species were not apparent by July 2002 as the tree canopies developed. In 2003, concentrations of TNC under honey locust tended ( $P < 0.10$ ) to be greater at mid-slope positions in May and were greater ( $P < 0.05$ ) in June. Forage from under walnut trees had greater TNC at the shoulder-slope positions over the season. Walnut trees at shoulder slopes were smaller than honey locust trees and allowed more light to reach the forage canopy. This may have boosted TNC concentrations at those sites given the high rainfall and cloudy skies of the 2003 growing season.

Forage from under walnut trees had  $20 \text{ g kg}^{-1}$  more ( $P < 0.01$ ) TNC than forage from under locust trees during May 2002 (Table 5). By July 2002, TNC concentrations were greater in forage from under honey locust trees (species  $\times$  date interaction,  $P < 0.01$ ). In 2003, TNC was about  $10 \text{ g kg}^{-1}$  greater ( $P < 0.05$ ) in forage from under walnut trees at both the May and June harvests but levels were similar between species in July. These data are indicative of the increasing density of the tree canopy May to July. Honey locust develops leaves earlier in the season than black walnut and had just begun leafing out at the time of the May harvest in each year.

Averaged across each season, TNC concentrations decreased ( $P < 0.01$ ) with increased tree density (Table 5). The effect of tree density on forage TNC increased at each harvest (density  $\times$  date interaction,  $P < 0.01$ ) in 2002, but in 2003 the gain in TNC levels from low to high tree density was similar (about  $20 \text{ g kg}^{-1}$ ) at all harvests. The negative relationship between TNC and tree

**Table 5.** Total nonstructural carbohydrate concentrations in a mixed sward in response to main effects of slope position, tree species, and tree density.

	Slope position†				Tree species‡			Tree density§			
Harvest	Toe	Mid	Shoulder	LSD¶	BW	HL	LSD	Low	Med	High	LSD
<hr/>											
g kg <sup>-1</sup>											
<hr/>											
2002											
May	89.0	83.5	81.0	NS	94.5	74.5	6.1	89.1	81.1	83.3	5.2
June	78.3	65.6	66.9	NS	68.6	72.0	NS	72.8	69.2	68.8	NS
July	69.7	72.5	74.9	NS	69.9	74.8	4.8	83.0	71.4	62.8	4.2
Mean	79.0	73.9	74.3	NS	77.7	73.8	3.3	81.6	73.9	71.6	3.5
LSD	9.2	8.3	9.7		6.0	NS		7.9	NS	8.0	
2003											
May	66.1	66.7	61.8	NS	69.2	60.5	8.6	77.4	61.5	55.6	NS
June	94.8	99.8	106.9	NS	105.1	95.9	5.3	109.1	101.9	90.5	7.3
July	69.5	68.3	68.5	NS	67.9	69.6	NS	80.8	63.7	61.7	5.4
Mean	76.8	78.2	79.1	NS	80.8	75.3	3.2	89.1	75.7	69.3	6.5
LSD	12.3	15.3	13.9		11.7	11.1		11.8	12.2	13.0	

† Toe = 3 to 5% slope at base of hill, Mid = 10 to 15% slope at side of hill, Shoulder = 3 to 5% slope at top of hill.

‡ Tree species were black walnut (*Juglans nigra* L., BW) and honey locust (*Gleditsia triacanthos* L., HL).

§ Low density = almost full exposure to sunlight, low shade environment; Medium (Med) density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

¶ For all treatment means,  $\alpha \leq 0.05$ .

(shading) density agrees with studies from both tropical (Samarakoon et al., 1990) and temperate (Belesky et al., 2006) environments.

The potential impact of changes in TNC to grazing animals is unclear. Animals prefer forages with greater TNC (Ciavarella et al., 2000; Mayland et al., 2000; Fisher et al., 2002), and even changes as small as 10 g kg<sup>-1</sup> of TNC between forages are sufficient to affect animal selection (Burritt et al., 2005). However, performance of animals in maturing silvopastures has received little research attention. Furthermore, while reduced TNC with shading is to be expected, this may be offset by increased forage digestibility (Garrett and Kurtz, 1983). As pastures are typically energy-limiting for livestock, TNC levels (relative to that of open pasture) may have potential to serve as a guide for pruning and thinning and supplementation decisions.

### Crude Protein

Concentrations of CP were greater ( $P < 0.05$ ) in forage from toe-slope positions in 2002 (Table 6). This was largely due to the strong effect of slope in June 2002 (slope  $\times$  date interaction,  $P < 0.05$ ) and likely reflects the better moisture status at toe slopes given a persistent water deficit in 2002. Slope position did not affect CP levels in 2003, perhaps due to the greater precipitation and cloudy conditions from that year.

Crude protein concentrations were similar by species and density in May and June 2002; in July, CP concentrations decreased with increased tree density under locusts but increased with density under walnuts (species  $\times$  density  $\times$  date interaction,  $P < 0.05$ ). In 2003, CP in forage from under walnut trees averaged about 10 g kg<sup>-1</sup> less ( $P < 0.05$ ) than that from under locusts. As with changes in NDF concentrations, this effect of species in 2003 may be attributable to the greater contribution of leguminous plants to sward biomass.

Crude protein concentrations tended ( $P < 0.10$ ) to increase with tree density in each year, although the change with each increase in tree density was often less

than 5 g kg<sup>-1</sup>. Shaded plants often have greater concentrations of CP (Kephart and Buxton, 1993; Wilson, 1995, 1996), thus greater CP concentrations in forage would generally be expected with increasing tree density. Strongest ( $P < 0.05$ ) responses to density were observed in June 2002 and May 2003. Between the two tree species, changes in CP concentration were similar with density at the May and June 2002 harvests, but in July 2002, CP concentrations decreased with density under honey locusts (species  $\times$  density and species  $\times$  density  $\times$  date interactions,  $P < 0.05$ ).

### Minerals

#### Calcium, Phosphorus, Magnesium, and Potassium

Forage Ca, P, and K concentrations were greater ( $P < 0.05$ ) at toe-slope positions in 2002, likely due to greater moisture availability (Fig. 2). Forage Mg was unaffected by slope. No differences by slope position were observed in 2003, likely due to more uniform soil moisture and to limestone and fertilizer applications in October 2002.

Within each year, forage from under black walnut trees had less ( $P < 0.05$ ) Ca than forage from plots under honey locust trees (4190 vs. 4770 mg kg<sup>-1</sup> in 2002 and 7180 vs. 7560 mg kg<sup>-1</sup> in 2003). Species  $\times$  date interactions ( $P < 0.01$ ) observed each year were largely due to differences in magnitude by harvests. While reasons for these differences due to species might be tied to dissimilarities in the cycling and redistribution of Ca to the soil surface by the trees, no differences in soil Ca were observed between species in samples collected in August 2002 (Buerger et al., data not shown). Botanical composition may have been a factor in forage Ca levels in 2003, given more leguminous plants observed in swards under locust trees (Buerger et al., 2005). However, this seems unlikely because legumes were not observed under either tree species treatment in 2002. Moreover, forage P, Mg, and K concentrations were unaffected by tree species.

Over each season, forage mineral concentrations generally increased ( $P < 0.05$ ) with tree density (Fig. 3).

**Table 6. Crude protein concentrations in a mixed sward in response to main effects of slope position, tree species, and tree density.**

	Slope position†				Tree species‡			Tree density§			
Harvest	Toe	Mid	Shoulder	LSD¶	BW	HL	LSD	Low	Med	High	LSD
	g kg <sup>-1</sup>										
	2002										
May	132	125	127	NS	128	128	NS	126	131	128	NS
June	133	114	120	8	118	127	9	118	123	127	NS
July	140	137	140	NS	134	144	6	138	140	139	NS
Mean	135	125	129	6	130	128	NS	127	131	131	NS
LSD	5	6	8		6	4		7	7	8	
	2003										
May	141	125	129	NS	126	137	NS	124	134	137	10
June	169	155	155	NS	154	165	7	157	156	167	NS
July	164	149	150	NS	150	158	NS	152	154	158	NS
Mean	158	143	145	NS	144	154	8	144	148	154	NS
LSD	8	11	11		9	9		10	13	9	

† Toe = 3 to 5% slope at base of hill, Mid = 10 to 15% slope at side of hill, Shoulder = 3 to 5% slope at top of hill.

‡ Tree species were black walnut (*Juglans nigra* L., BW) and honey locust (*Gleditsia triacanthos* L., HL).

§ Low density = almost full exposure to sunlight, low shade environment; Medium (Med) density = morning sun exposure with shading events after solar noon, medium shade environment; High density = full to partial shading all day, high shade environment.

¶ For all treatment means,  $\alpha \leq 0.05$ .

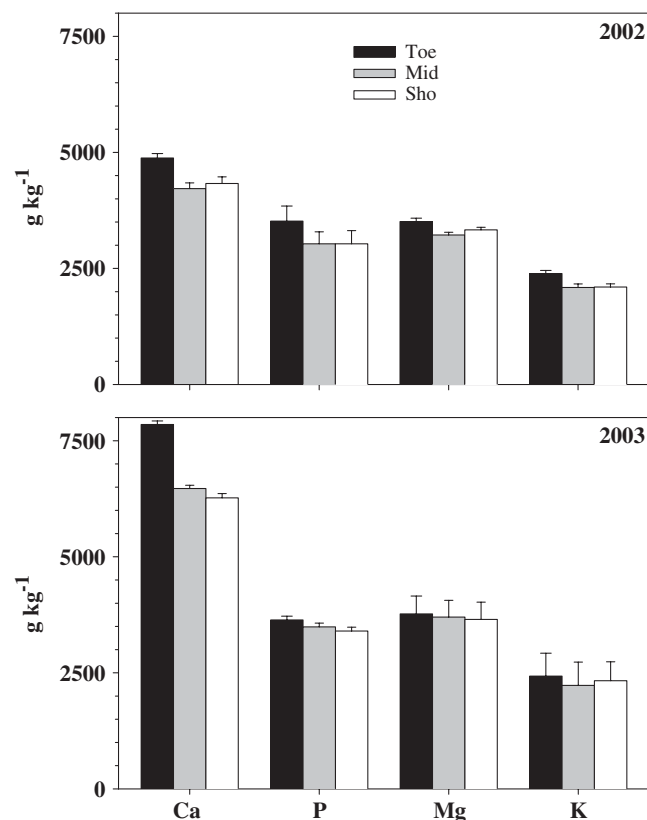


Fig. 2. Forage mineral concentrations ( $K = \text{mg kg}^{-1} \div 10$ ) in response to toe-, mid-, or shoulder-slope position in Appalachian silvopastures harvested in May, June, and July in 2002 and 2003. Calcium, P, and K concentrations were greater ( $P < 0.05$ ) at toe slopes in 2002.

These increases were not simply due to changes in nutrient concentration, because forage grown under medium density sites typically had both greater mineral nutrient concentrations and greater biomass yield (Buegler et al., 2005). Concentrations of both Ca and P increased in dry matter with successive harvests in 2003, but the increase was greater at toe slopes for Ca and at upper slopes for P in 2003 (slope  $\times$  data interaction,  $P < 0.01$ ) (Buegler et al., data not shown).

## CONCLUSIONS

The complexity of interactions between trees and forages makes silvopastoral design and management both interesting and challenging endeavors. Changes in response to treatment, especially for nonstructural carbohydrate, coincided with tree canopy phenology. The observed pattern of greater CP in forage under honey locusts was likely due to greater numbers of leguminous plants at those sites. Generally, NDF and ADF concentrations were lower while CP and mineral concentrations were greater at toe-slope positions. Trees in pastures caused apparent trade-offs in measures of forage nutritive value. As tree density increased, slight reductions in NDF were coupled with larger reductions of TNC, yet forage mineral concentrations were generally greater with increased tree density. The implications of these

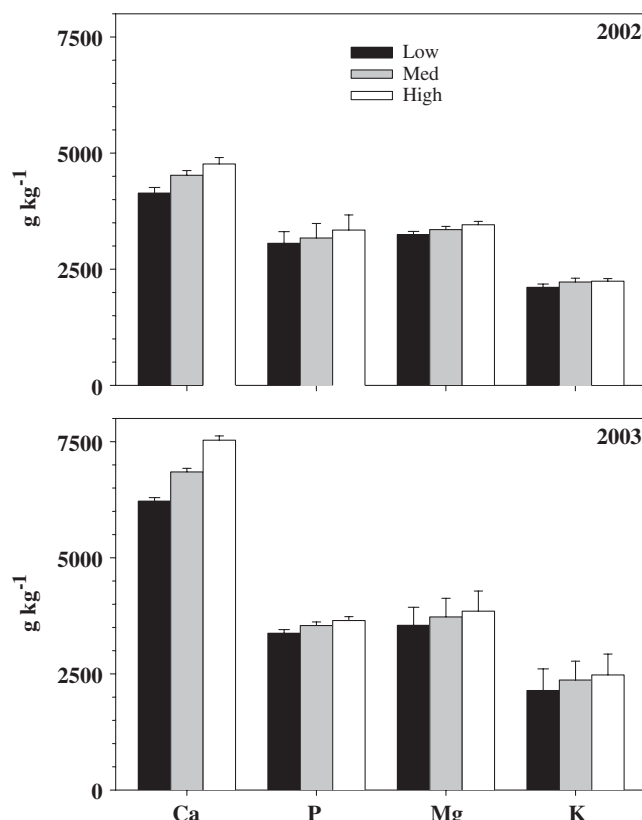


Fig. 3. Forage mineral concentrations ( $K = \text{mg kg}^{-1} \div 10$ ) in response to low, medium, or high tree density in Appalachian silvopastures harvested in May, June, and July in 2002 and 2003. Calcium and P concentrations increased ( $P < 0.05$ ) with density in 2002. Concentrations of all minerals increased ( $P < 0.05$ ) with density over the 2003 season.

interactions for livestock production are unknown: It is plausible that reductions in NDF, increases in minerals, and potential improvements in both fiber digestibility and animal comfort due to shade may offset the negative effects of reduced forage nonstructural carbohydrates. However, this remains questionable as energy is frequently the limiting factor for animal production in forage systems in full sun, and further research is warranted.

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